REPORT DOCUMENTATION PAGE

Form Approved

OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 11, 2008	Final (9/21/06 – 9/20/07)

4. TITLE AND SUBTITLE
Trip Report, APLIS 07, Spring 2007, Beaufort Sea

5. FUNDING NUMBERS
N00024-02-D-6602/0080

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
SUBRON FIVE DET ASL
140 Sylvester Rd.
San Diego, CA 92106-3521

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The ICEX/APLIS (Applied Physics Laboratory Ice Station) 2007 project was a two-sponsor project for APL/UW. The primary sponsor was the Navy with the Arctic Submarine Laboratory as their project coordinator. The secondary sponsor was the National Science Foundation with VECO Polar Resources as their project coordinator. The Navy project at APLIS involved two submarines that operated on the APLIS underwater tracking range: USS Alexandria (SSN 757) and the Royal Navy submarine HMS Tireless (S 88). The NSF project primarily involved study of sea ice mechanics. Scientists deployed GPS recording and Argos reporting buoys to monitor ice-floe motion over a large area. The ice camp lasted from 3/2/07 to 4/16/07. This informal report presents information on the logistics and environmental measurements (CTD, weather, and floe drift) as well as appendices on some ancillary tests conducted at the camp.

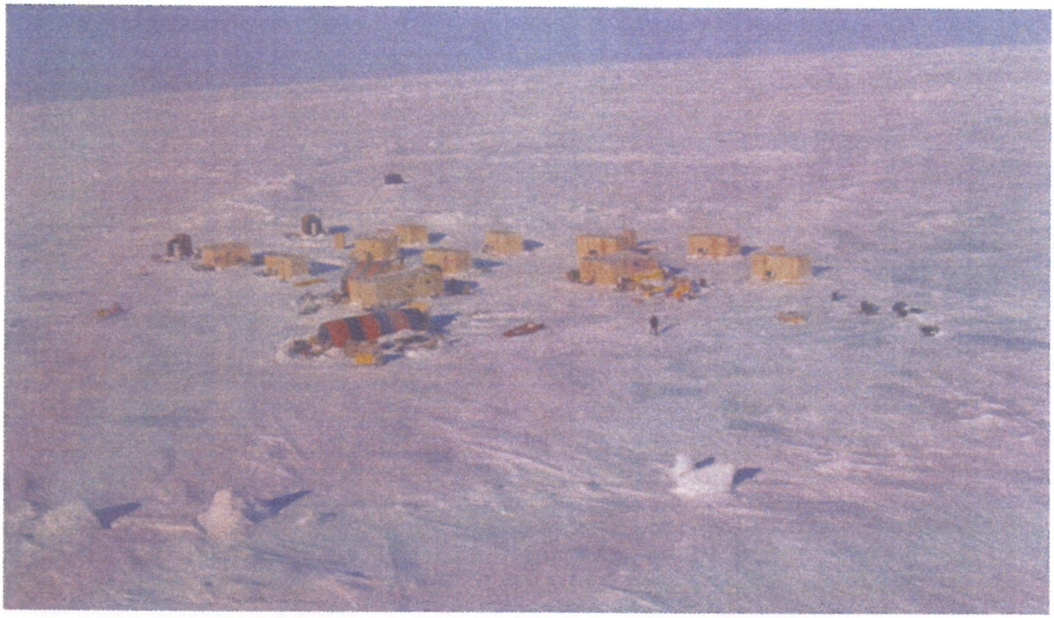
14. SUBJECT TERMS	15. NUMBER OF PAGES
ice station, ice floe motion, tracking range, Beaufort Sea	23
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

Final Technical Report
NAVSEA Contract N00024-02-D-6602/0080

Trip Report
APLIS 07
Spring 2007, Beaufort Sea

by
Fred Karig
Timothy Wen



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1. Introduction

The ICEX/APLIS (Applied Physics Laboratory Ice Station) 2007 project was a two-sponsor project for APL/UW. The primary sponsor was the Navy with the Arctic Submarine Laboratory as their project coordinator, and the secondary sponsor was National Science Foundation with VECO Polar Resources as their project coordinator.

The Navy project at APLIS (Applied Physics Laboratory Ice Station) involved two submarines – the USS Alexandria (SSN 757) and the Royal Navy submarine HMS Tireless (S 88) which operated on the APLIS underwater tracking range.

The NSF project was primarily involved with the study of sea ice mechanics. Scientists deployed GPS recording and Argos reporting buoys to monitor ice floe motion over a large area.

The ice camp lasted from 3/2 to 4/16. This informal report presents the environmental measurements, i.e., CTD, weather, and floe drift, and appendices on some ancillary tests conducted at the camp.

2. APLIS build-up

The first field group of 4 APLIS personnel departed Seattle 2/26 to establish sleeping quarters in the SeaAir Building at the Deadhorse Airport in Prudhoe Bay Alaska. An additional 18 x 40 ft insulated and heated tent on the tarmac behind the SeaAir building was erected for transient project personnel to sleep in. These quarters were needed as the recent pipeline failures and their repair brought in so many workers there was no vacancy at the Prudhoe Bay Hotel. The logistics headquarters, including communications, for the project were in the SeaAir building. Meals were supplied by the Prudhoe Bay Hotel.

Arctic Submarine Lab personnel were responsible for manning the shore logistic base including communications, loading aircraft, and local transportation from the start on 1 March thru the Navy sponsored portion of the camp. APL personnel were responsible for those tasks during the NSF and demobilization portion of the camp.

Reconnaissance flights for a campsite started on 3/1 using a ski-equipped Cessna 185 from Arctic Air Alaska and the Cessna Caravan on wheels from Wright Air Service. Both firms are based in Fairbanks, Alaska. Satellite imagery provided by the Navy Ice Center showed remnants of multi-year ice 100 nm from shore. An initial landing was made at a nominal distance of 150 nm from shore on a smooth piece of ice with little snow cover to allow a refueling and to get a measure of ice thickness vs. snow cover depth. The ice was 18 inches thick and the snow cover was 1 inch thick, which was about normal. Additional searching found a medium sized floe, about one mile by one mile, with strong multiyear features and a candidate runway basically N/S on one side of it. A landing on a smooth portion of the first year ice and a short hike over to some

rougher and deeper snow covered first year ice showed a thickness of 4.5 ft and about 6 inches of snow cover with a few spit ups of young ice that had gathered more snow. The position of the landing was 73°07.46' N and 144°53.37' W. This area looked promising but when observed from the air on leaving the area it was evident that moving several hundred yards to the southwest would be better.

The next day both aircraft landed at the new site using the rough candidate runway. The area was selected for the camp and runway after a quick visual survey. The runway area was also 4.5 ft thick with typically 6 inches of snow cover. On this flight the Caravan carried the Alpine snowmachine, the small packer/leveler, a drum of Jet A, runway marking materials, and basic survival equipment for 2 APL field personnel to spend the day. Starting the next day the Caravan made 56 flights for the build up and Navy activities. On 3/4 the runway was improved to over 2000 ft long, and a CASA 212-200, provided by Big Horn Airways of Sheridan Wyoming, started making cargo flights. It flew a total of 48 sorties.

The first overnight stay at camp for 6 APLIS field personnel was on 3/6 after 4 days of day trips to get three 8x20 buildings up and heated. Additional field workers arrived on 3/7 (3 Navy and 1 APL) and stayed at camp. Aircraft activity was generally 3 CASA and 2 Caravan flights per day for 14 days to bring out personnel, fuel, food, experimental equipments, and building materials. The total amount of material flown out in the supply period was nominally 175,000 lbs.

The camp (Figure 1) consisted of a dining tent (18x15) attached to a plywood cookhouse (16x28), a plywood control building (20x20), a generator/workshop tent (12x30), 8 plywood sleeping quarters (8x20), a divers quarter (20x16), 2 tent sleeping quarters (8x20), a tent on sled runners (8x8), a helicopter transportable plywood hut (8x8), and several unheated outhouses. Surface transportation was provided by 3 Alpine and 2 lightweight snowmachines with appropriate cargo sleds. There was an APL hole melter system at camp to support making holes of diameters larger than 8 inches and did in fact make an 18 inch diameter hole thru 40 ft of rafted ice for the Naval Postgraduate School students' experimental work.

Communications consisted of Iridium (voice and email) and Inmarsat phones for long haul, VHF-AM for aircraft, VHF-FM for camp and ice area use, and underwater communications equipment to work with the submarine.

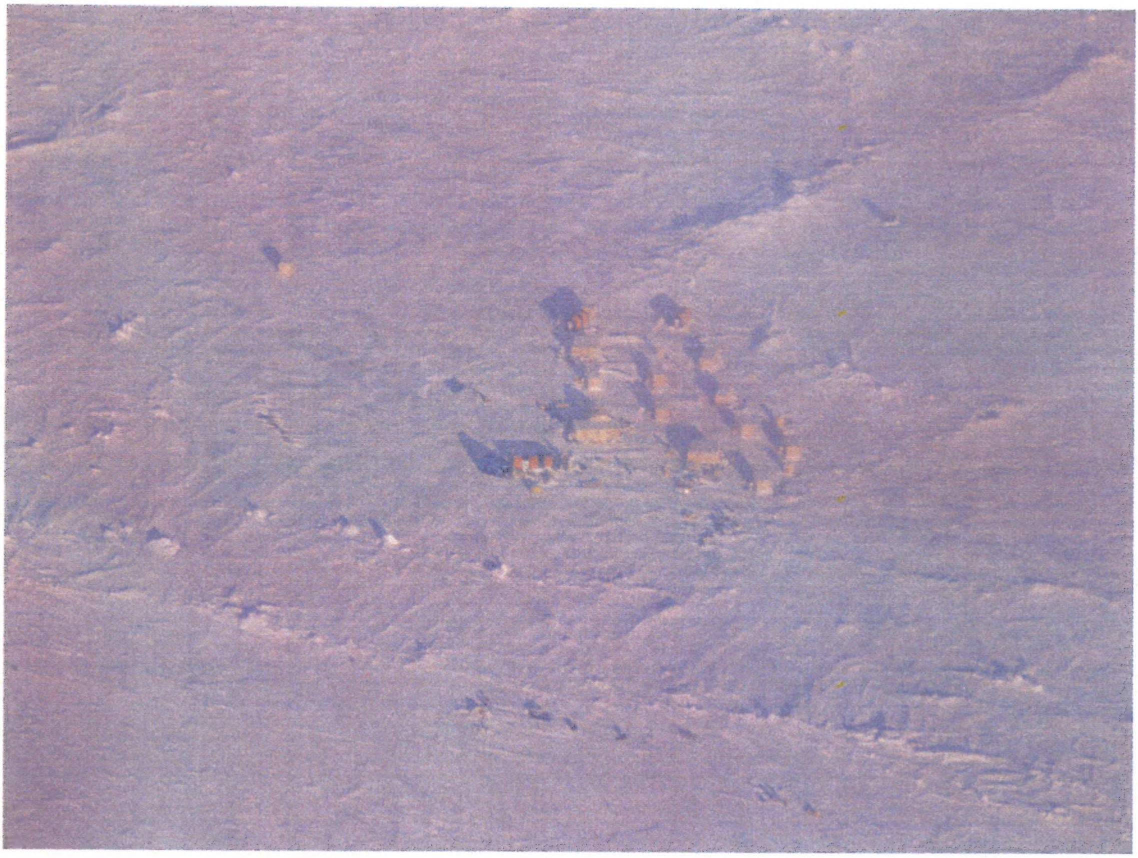


Figure 1. Aerial view of APLIS 07. Runway is at the bottom.

3. Navy project (ICEX)

Four more APL personnel arrived at the camp on 3/10 to set up an underwater tracking range for the submarines arriving on 3/15 and 16. The Navy project at APLIS involved the two submarines – the USS Alexandria (SSN 757) and the Royal Navy submarine HMS Tireless (S 88). Range safety of the submarines were handled by personnel from the Arctic Submarine Laboratory.

The Navy sponsored VIP visits were on 3/17-18 and 24-25 and were supported by an additional Caravan aircraft from Wright Air Service. The camp helicopter was a Bell 212 supplied by ERA Helicopters of Anchorage, Alaska, and was at camp from 3/13 until 4/13 supporting both the Navy and the NSF activities. The camp loading for the Navy portion totaled 763 man-days, of which 287 were by APL personnel and the helo crew of 3.

There was an explosion on the HMS Tireless on the evening of 3/20 in which two crewmen were killed and a third was seriously injured. The injured person was subsequently removed from the vessel and transported to the ice camp by snowmachine and then flown to Prudhoe Bay by the project helicopter. He was then flown to

Anchorage for more care by the Alaska Air National Guard C-130 Medivac aircraft. The deceased crewmen's bodies were brought to camp that evening and flown by the Caravan the next day to Prudhoe Bay. The Tireless stayed in the vicinity of camp for a day checking out systems and then departed. She made homeport with no problems. After completing its testing on schedule the Alexandria left the camp area on 3/29. All the Navy staff, APL range personnel, and their equipments were evacuated from the camp by 3/31 and the first of the NSF science personnel arrived.

4. NSF project

The NSF scientists were primarily involved with sea ice mechanics and deployed about 25 GPS buoys to monitor ice motion. The buoys were designed to upload the data to Argos satellites in real time and have a life of 2 years or more and will not be recovered at the end of the experiment period. Local camp-based activities included a GAVIA AUV (http://www.gavia.is/) which swam under a 1st year ice ridge to photograph and acoustically map it for studying ridge structure. Divers also took measurements and photos of the same underwater portion of the ridge. The divers, 3 of APL and 2 of NSF, were also available to recover the AUV but were not needed since the AUV was run on a tether. Another experiment was an EM "bird" flown under the helicopter to map the thickness of the ice cover. It made runs out to 100 nm or more from the camp. During the experiment period of 4/1 to 4/14 up to 30 scientists and 10 APL/Helo crew personnel were at the camp for another 436 man days.

The camp was demobilized over a 2 day period using two Caravan Aircraft and evacuated on 4/16 with all personnel off the ice and reusable equipments returned to Prudhoe Bay for truck shipment back to Seattle.

5. Weather

Weather data were logged for scientific as well as logistic needs. A weather station was deployed at 8 m altitude and data were transmitted to a PC in real time via an RS232 link, then displayed and stored. The display was updated every 30 sec and the data were stored every 5 min. Figure 2 shows the data for the entire camp period. The wind direction, as recorded, was relative to magnetic North. An average of 26.5° magnetic variation was used to convert the wind direction from magnetic to true.

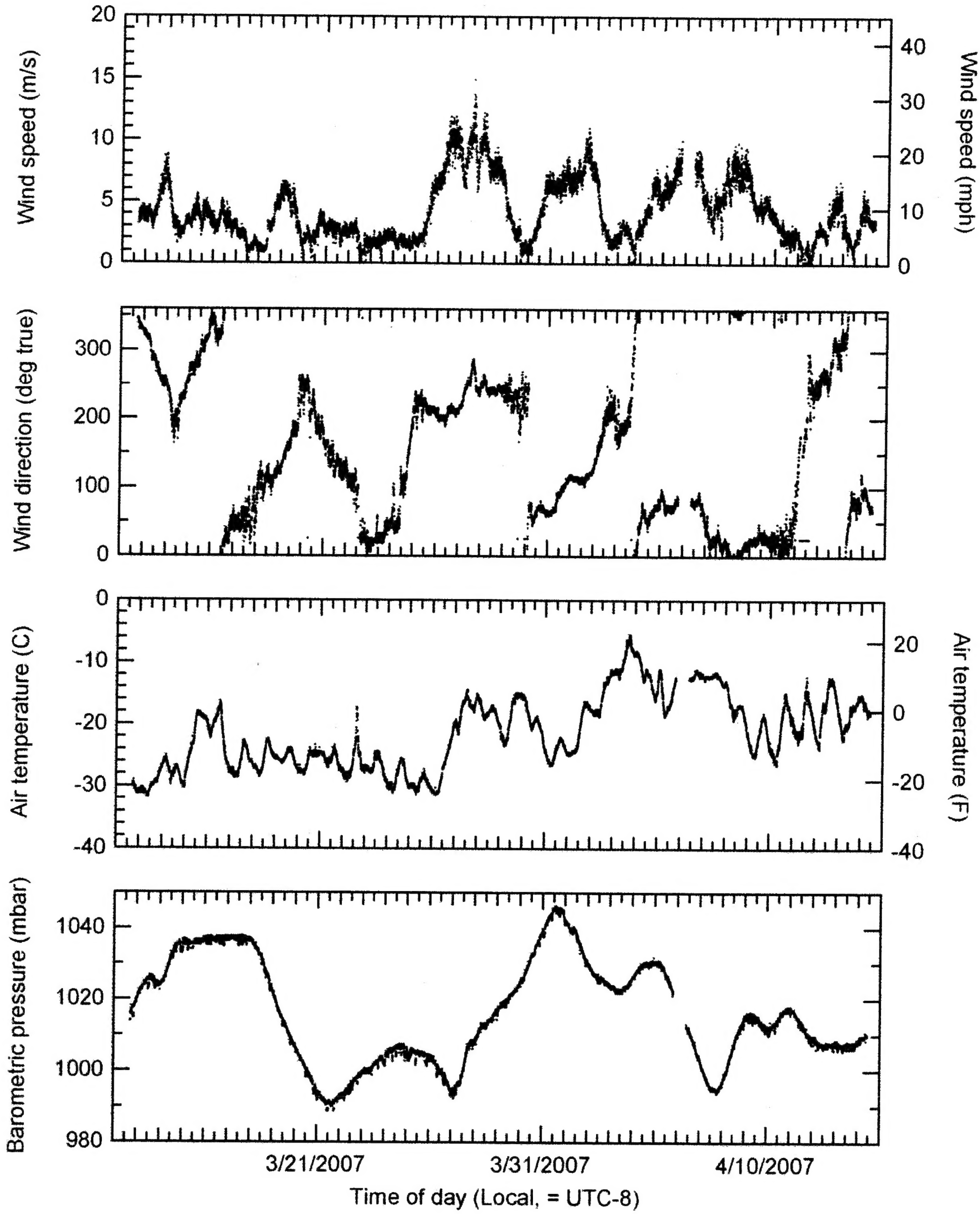


Figure 2. APLIS 07 weather data.

6. Floe drift and rotation

The floe the camp was on drifted a fair amount during the camp period as shown in Figure 3. The drift was mainly wind-driven as shown in Figure 4 . When the ice was dense initially, there wasn't much rotation associated with the drift. However, as the season progressed and ice started breaking up, rotation of up to 8° was measured (Figure 5).

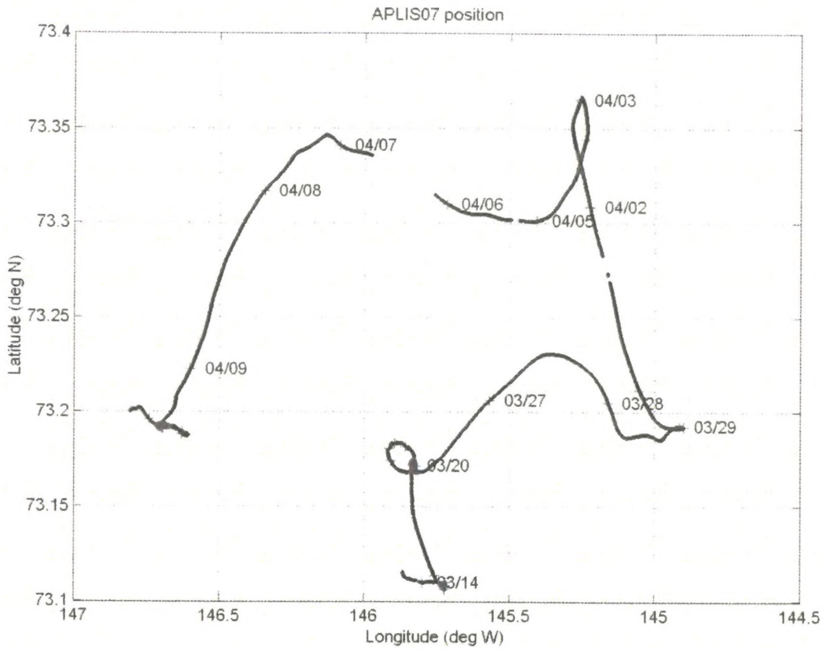


Figure 3. APLIS 07 drift track. Each + symbol denotes the 00:00 UTC of each day. At the latitudes shown, each degree of longitude is approximately 32 km.

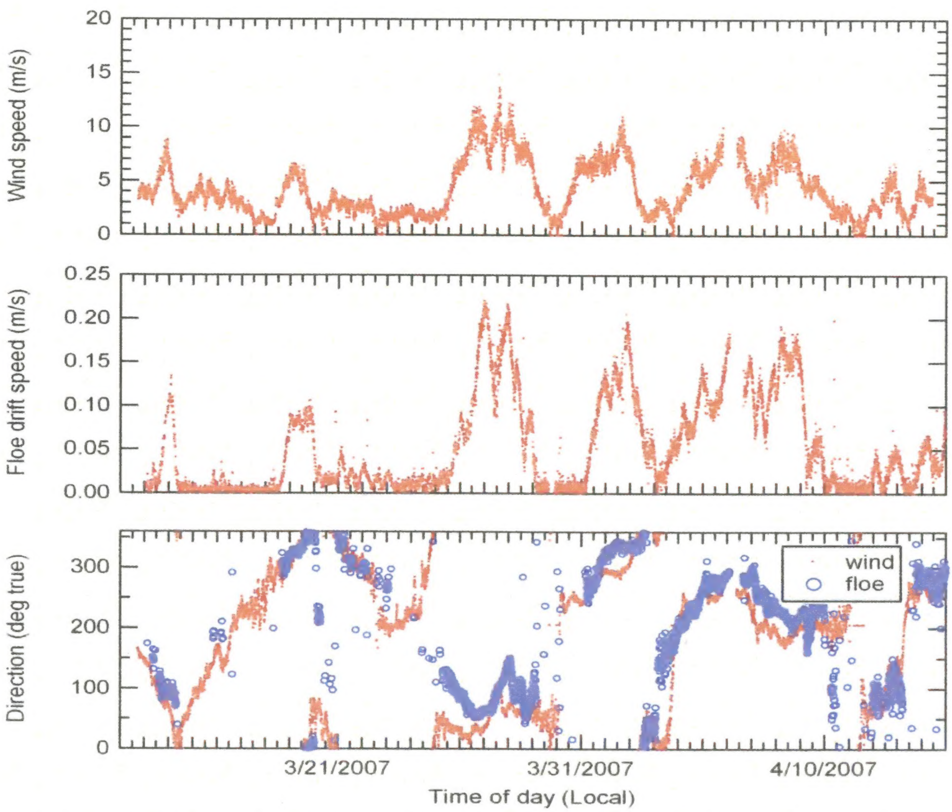


Figure 4. Comparison of speed and direction of the floe drift and wind. The wind direction has been converted to "to".

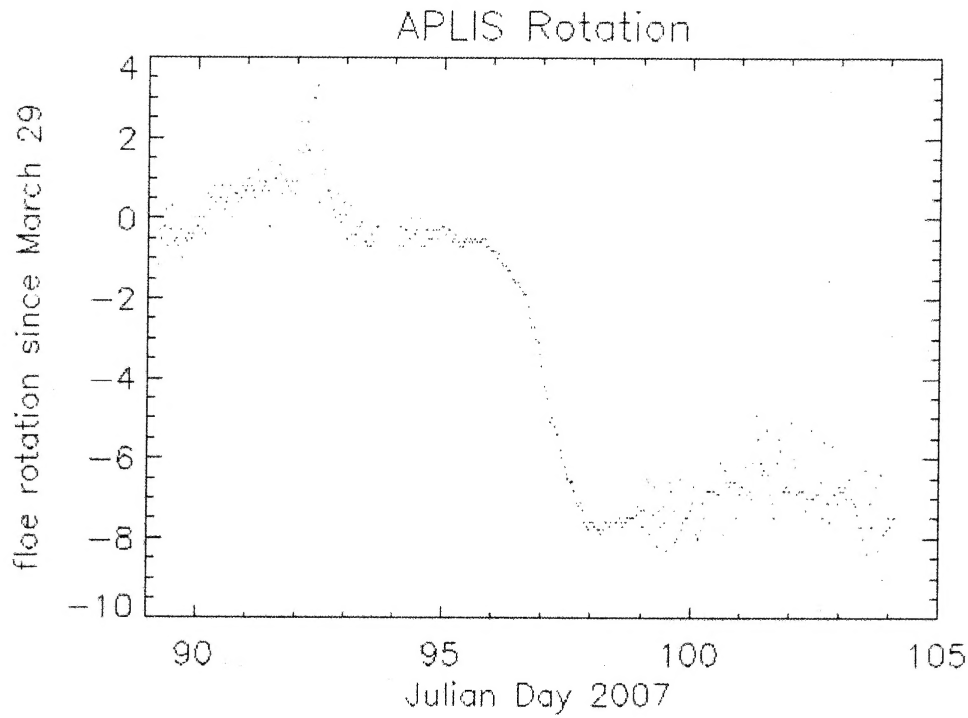


Figure 5. Rotation of ice camp floe after 3/29 (Jenny Hutchings, University of Alaska, Fairbanks)

7. Underwater tracking range

An underwater tracking range was set up to track the two submarines during the Navy phase. The range layout is shown in Figure 6. Hydrophones were deployed at 100ft depth. The +Y axis was aligned with the true north to facilitate submarine navigation under ice. This year the alignment was achieved using GPS receivers. A Garmin-15H GPS receiver and a radio modem were placed at the same location as hydrophone #1 and GPS fixes were telemetered to the camp. By comparing the fixes with those obtained with another receiver at the (0,0) of the camp, the true bearing of hydrophone #1 could be computed. The range was then "rotated" to give hydrophone #1 the same bearing in the XY coordinate system, resulting in +Y axis being aligned to the true north.

The bearing was later checked using the traditional method : (1) setting up a transit directly above the (0,0) on top of the control building for sun sights, and (2) using a computer program (Multi-year Interactive Computer Almanac, 1800-2050) to compute the azimuth of the sun. Sun sights were taken a few times for comparison with the GPS method and their results generally agreed to 0.1°.

Floe rotation was monitored daily and the information passed to the submarines. The rotation during the Navy phase was small, on the order of 0.5° or less, CW and CCW.

The tracking this year suffered from the same problems we encountered in 2003: noisy tracking pulses and a receiver with too much gain. Unfortunately these problems were not addressed beforehand due to personnel changeover. Due to circumstances beyond our control, the tracking pulse generation system installed on HMS Tireless could not be checked out until she arrived at APLIS. At that time the 2008 system failed, necessitating a change to a back up system. This system did not accept the tracking interface pulses properly and the pulses transmitted were just the precursor noise (see Appendix A).

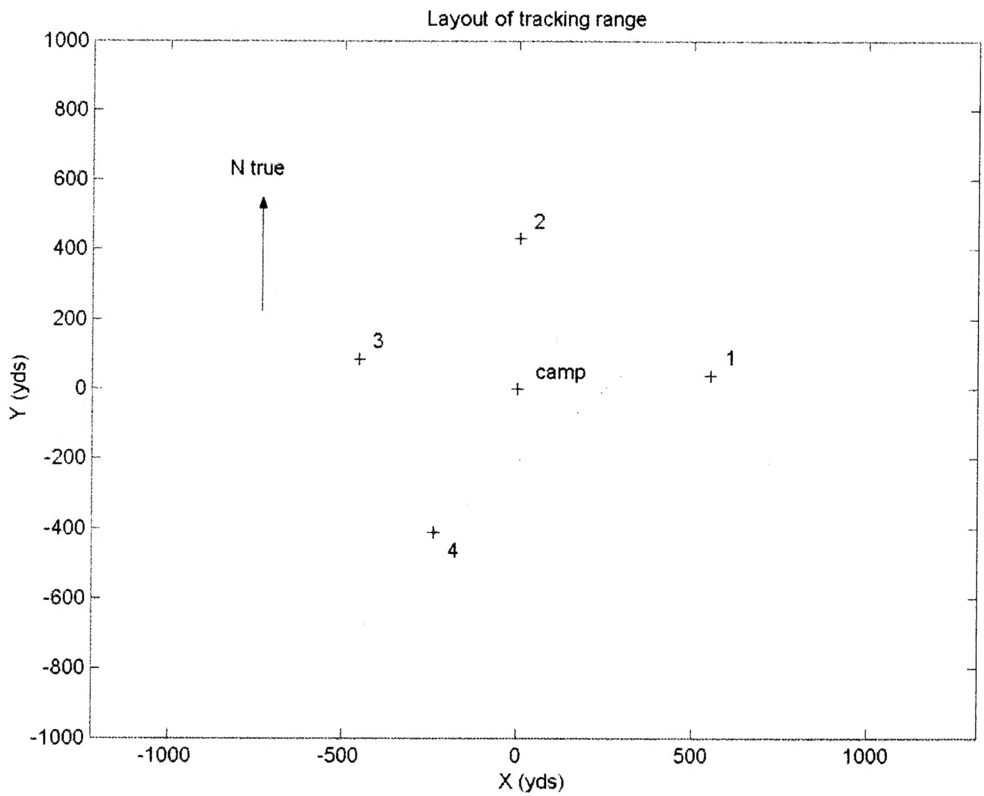


Figure 6. Layout of the range. The (0,0) of the range is a hydro hole at the camp. Numbers 1-4 marked the location of the tracking hydrophones. The +Y axis was aligned with true north initially but rotated up to +/- 2 deg during the Navy period. Dashed line denotes the runway.

8. CTD

CTD casts were taken at the camp and sound speed profiles were derived from the data. The profiles were then used for ray-tracing and for obtaining an average sound speed for the tracking range.

The casts were taken with a SeaBird Sealogger25 sampling at 8Hz for high resolution. From the temperature, salinity, and depth, sound speed was derived using UNESCO algorithms. Casts were typically made down to 530 m. Figure 7 shows a typical cast

showing a thermal layer between 50 m to 90 m of depth. Due to constraints from the submarines operating in the area, only a total of 11 casts were made, at irregular intervals, during the Navy phase. Figure 8 is a plot of salinity profiles from 2003 and 2007, showing a fresher surface layer in 2007. A ray trace with source depth at 30.47 m (100ft), depth of the tracking hydrophones, is shown in Figure 9.

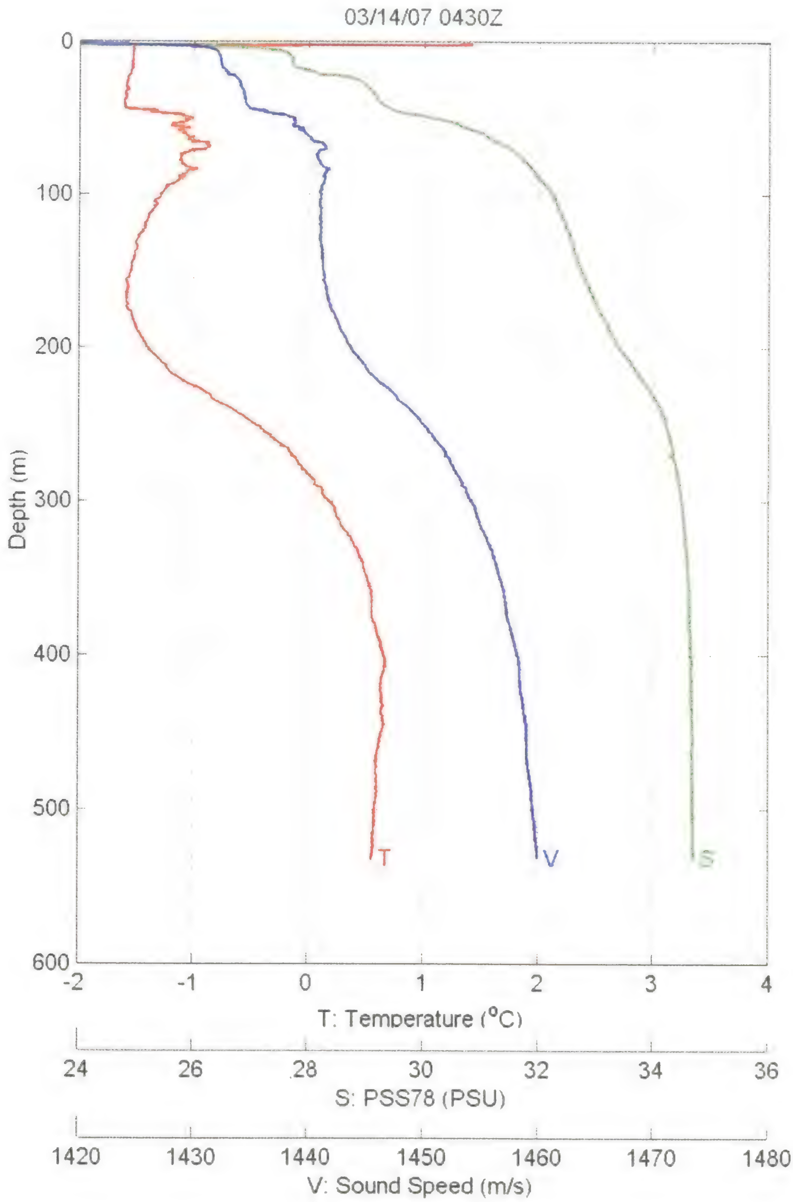


Figure 7. A typical CTD cast at APLIS07

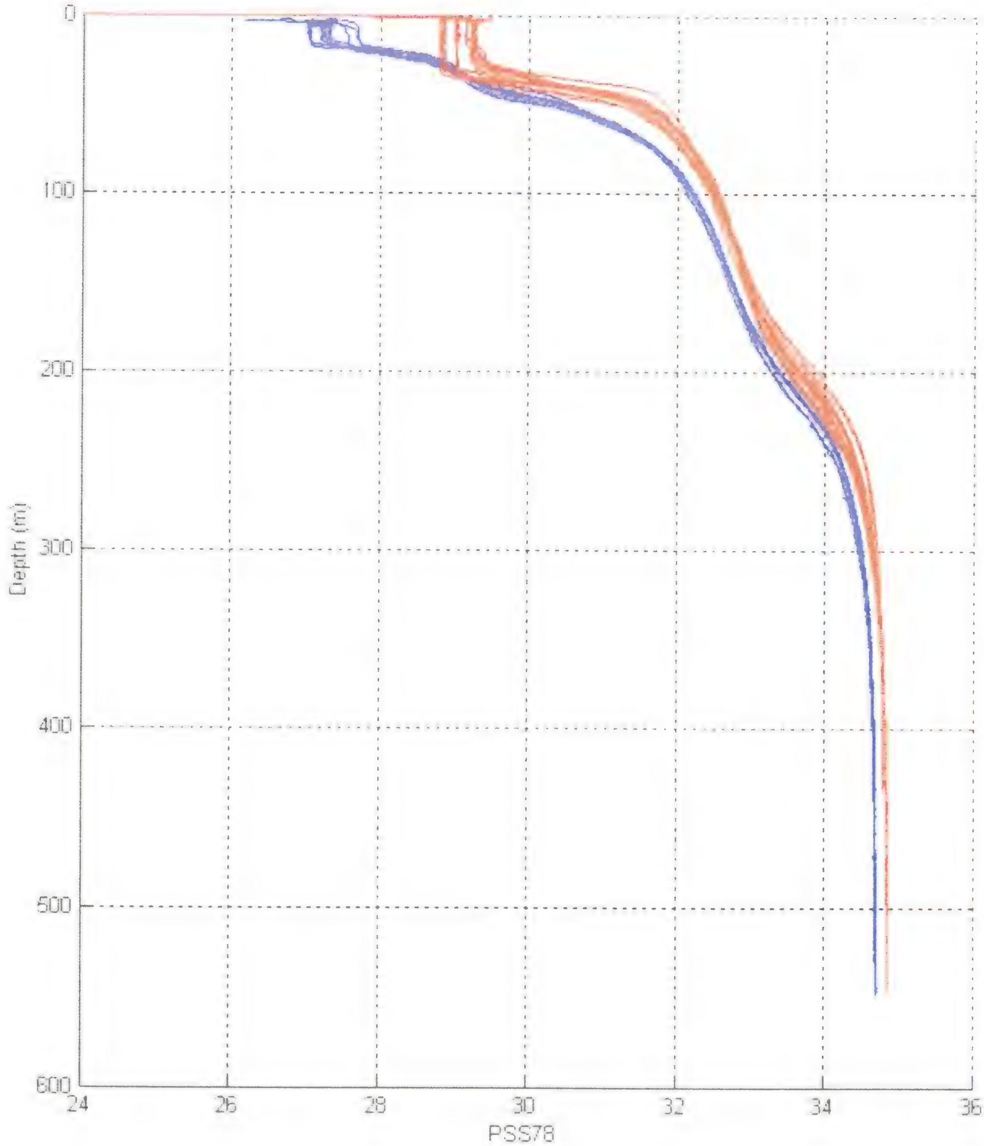


Figure 8. Comparison of APLIS 03 (red) and APLIS 07 (blue) salinity profiles from the same season showing a fresher layer of water in the upper 30m in 2007. An offset of ~0.2 PSU at deeper depths is most likely due to calibration error of the conductivity cells this year.

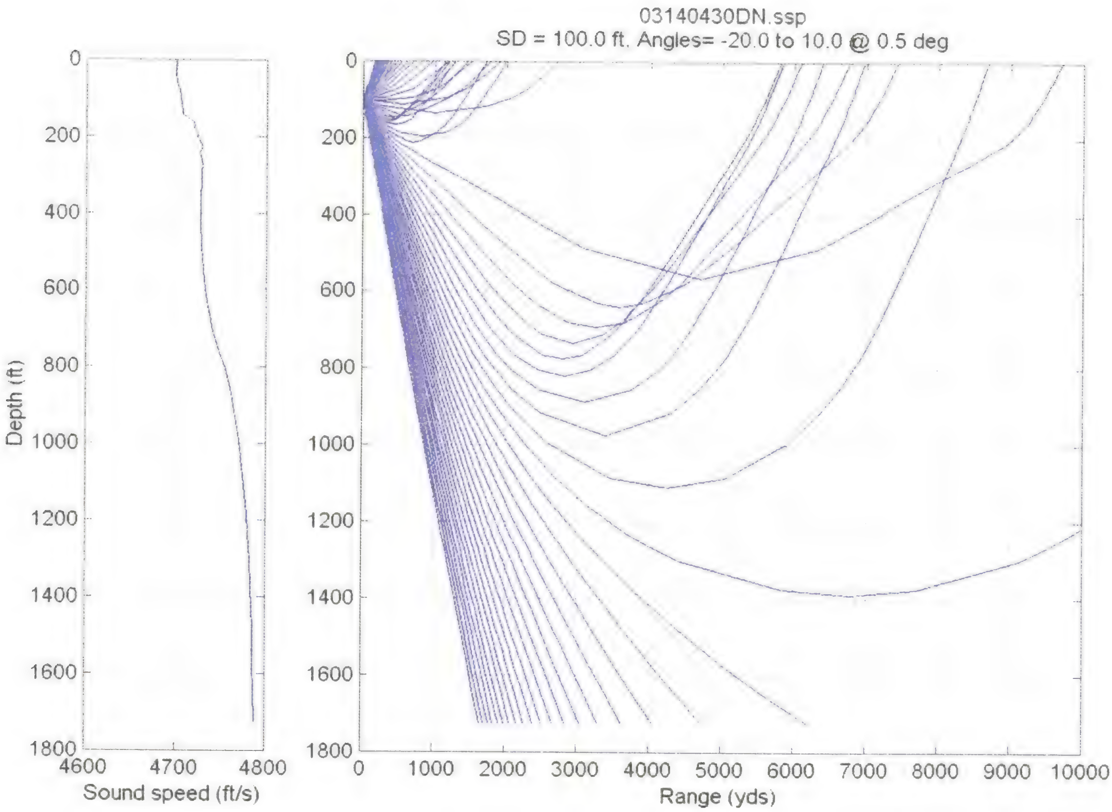


Figure 9. Ray trace using sound speed profile of 03/14 0430.

More CTD casts were taken with a Seabird SBE19 during the NSF project period by Jeremy Wilkinson[1]. Most changes in the temperature and the salinity structures took place in the upper 100m. Time series plots of some of the temperature and salinity profiles from both the Navy and the NSF projects are shown in Figure 10a & b for comparison. There are more profiles than shown, but only profiles a few hours apart are plotted. Bear in mind the casts were taken at different locations as the floe drifted.

[1] The Scottish Association for Marine Science
Dunstaffnage Marine Laboratory
Scotland, UK

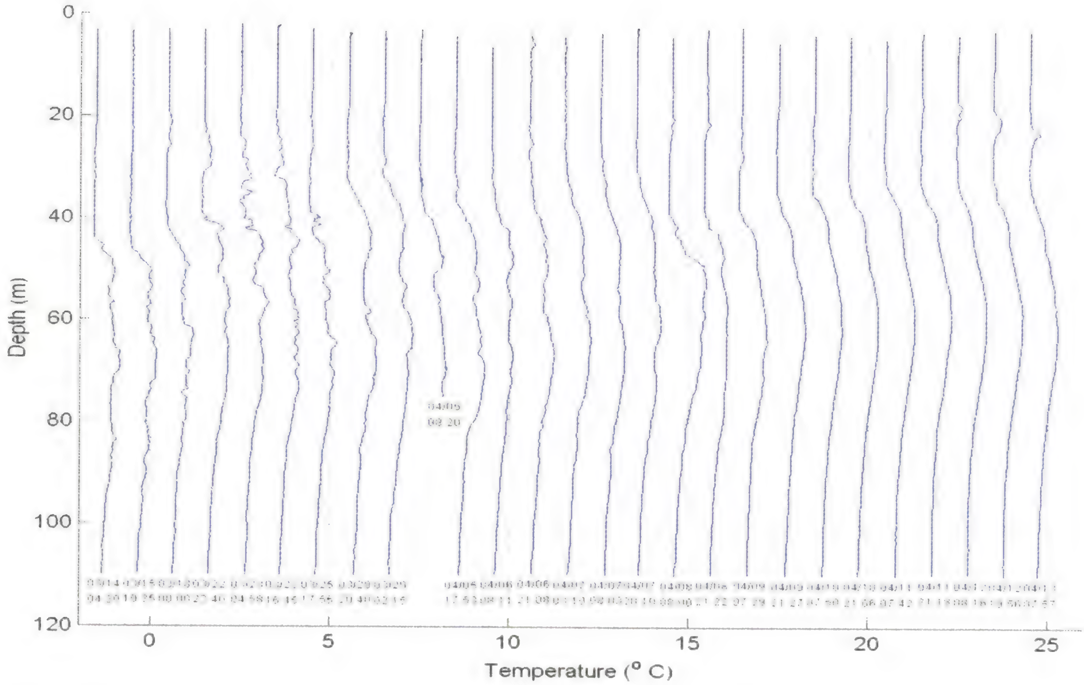


Figure 10a. Time series plot of selected temperature profiles. Each one is offset by 1 deg from the profile to the left. Time of day is UTC.

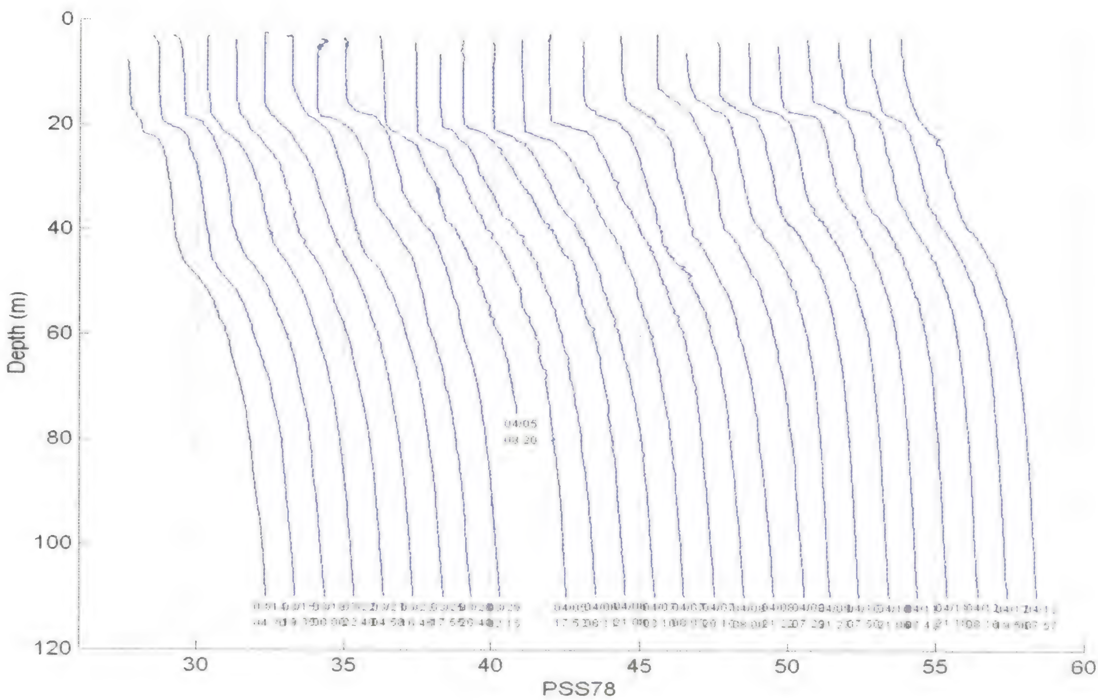


Figure 10b. Time series plot of selected salinity profiles. Each one is offset by 1 deg from the profile to the left. Time of day is UTC.

Appendix. A

Analysis of tracking pulses from USS Alexandria

The APL range uses tracking pulses 10 ms long for tracking submarines. To generate these pulses, a signal is injected into the underwater telephone part of the BSY-1 sonar system aboard USS Alexandria using the APL Underwater Telephone Interface, UQCI. The input signal consisted of two parts – precursor and main. The precursor was a very low amplitude 400-ms tone at 600 Hz, and the main part, the tracking pulse, was a higher amplitude 10-ms pulse at 2.3 kHz with a square envelope. The long 400-ms tone at 600 Hz gave the BSY-2 underwater telephone enough time to turn on and set an AGC. This tone was transmitted acoustically at a moderate level at 8.7 kHz . The 10-ms pulse injected at 2.3 kHz was transmitted at a maximum level at 10.4 kHz.

The receiving system had a 1.0-kHz bandwidth filter centered at 10.25 kHz that passed the 10.4-kHz signal but filtered out the 8.7-kHz precursor tone. With careful adjustment of the amplitude of the 600-Hz and 2.3-kHz signals, the 10.4-kHz tracking pulse would be a replica square envelope of the input. Otherwise, the leading edge of the envelope could have a slope and the top could be wavy. Unfortunately there was no time and resources to verify the precursor and the pulse properly at the time of dockside installation on Alexandria, other than quickly checking the pings with a hydrophone and receiver at dockside and viewing the highly reverberated signals on a scope.

Figure A-1 shows a typical received pulse. The main tracking signal was at the expected frequency of ~10.4 KHz, but the precursor was centered at 10 KHz, instead of 8.7 KHz. Since the precursor was now in-band, it was treated as a valid tracking signal by the receiver and ultimately caused some problems with pulse detection.

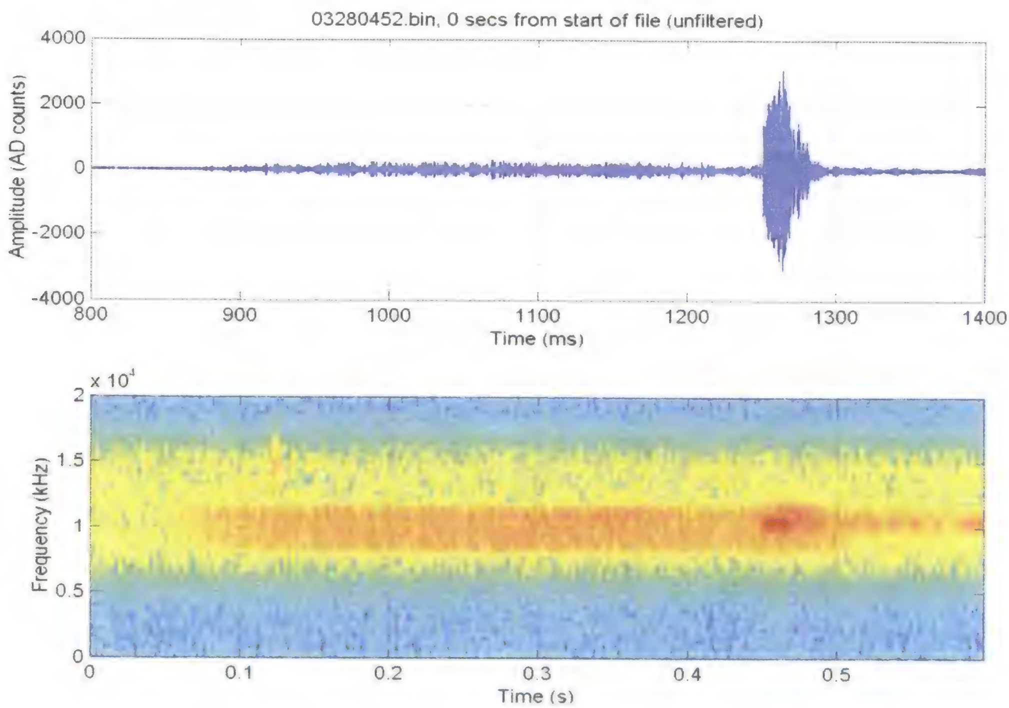


Figure A-1. Waveform and spectrogram of a typical received tracking pulse. The submarine was at ~2000 yards from the camp and approaching.

Figure A-2 shows the tracking pulse in Figure A-1 zoomed. The shape of the pulse shows the severity of multi-path interference. Figure A-3 shows the ping-to-ping variation of the pulses.

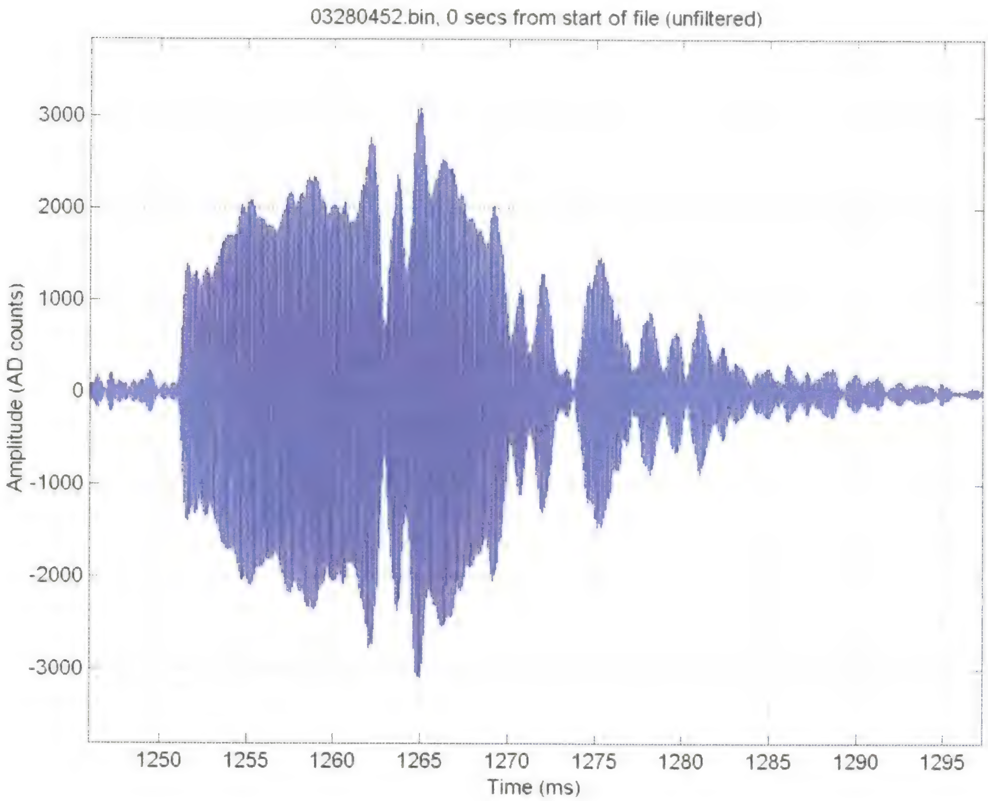


Figure A-2. Zoom of the pulse in Fig. A-1 showing multi-path interference. The transmitted pulse was 10 ms in length.

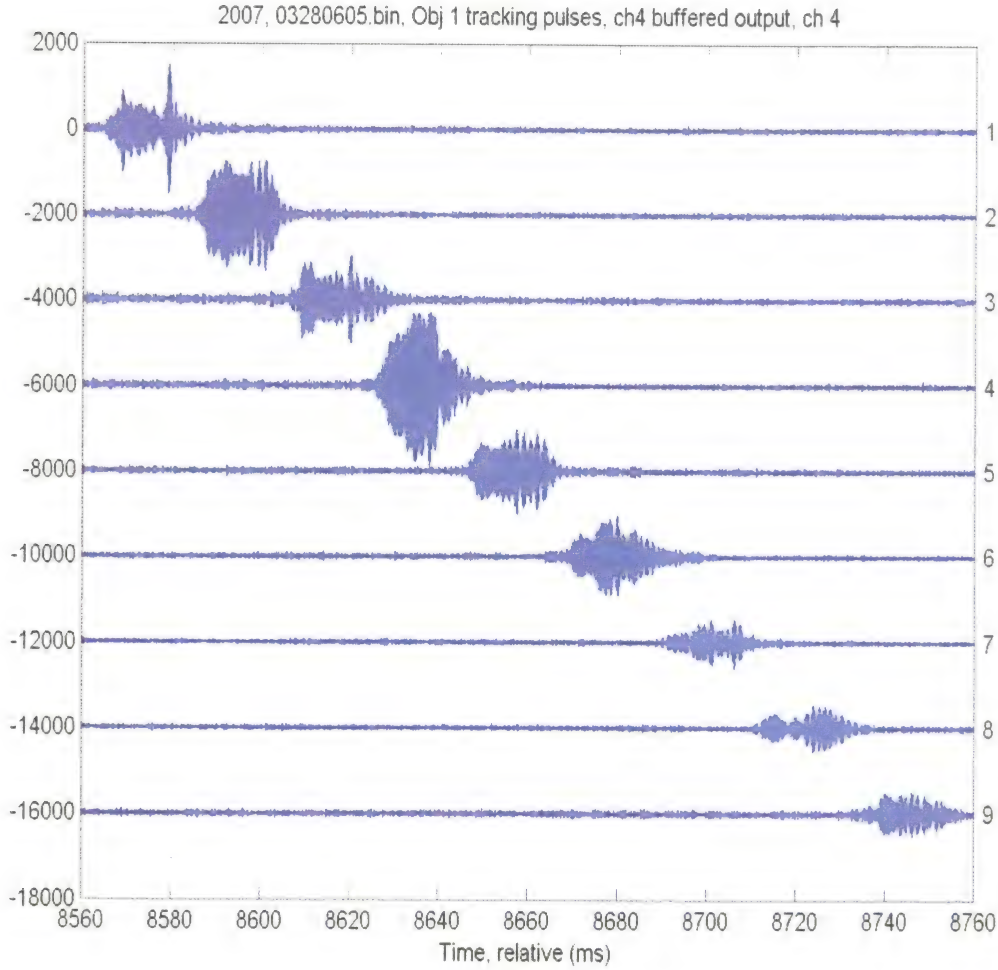


Figure A-3. Waterfall plot of received tracking pulse showing the ping-to-ping variability. The ship was at 2400 yards from the camp. Pulses were transmitted at 20 seconds apart.

Appendix. B

Candidate tracking pulse test

The APL/UW tracking range uses CW pulses for tracking. They work well in normal environments. In the presence of countermeasures ejected by submarines, however, the pulses are drowned out and the tracking is lost completely. To counter the problem, we tested 3 types of pulses that are thought to work well with countermeasures: linear frequency modulation, linear period modulation, and PSK. Each type again had pulses of different length and bandwidth (see Table B-1).

We originally planned to transmit the slew of test pulses from the HMS Tireless as she moved around the range at different depths and record the pulses received at the hydrophones. But due to her early departure, the plan was changed to transmitting the pulses from the (0,0) hydro hole in the camp and receiving at the hydrophones. The maximum range was therefore only on the order of 500 yards.

A DA generated the pulses which were then fed into a L2 instrumentation amplifier. The center frequency of the pulses was 10.25 KHz. The output of the L2 was then fed into a portable range pinger. The pinger transducer was lowered and raised continuously in the hydro hole between surface and ~70 ft while the pulses received at the hydrophones were filtered and digitized with an AD card (Microstar iDSC-1816) and recorded on a PC. The sample rate of the AD card was 102400 Hz with a band pass filter of 5012-15004.7 Hz. Four channels of signals were digitized:

ch0: DA output (+/- 0.1 Vpp)
ch1: hydrophone 1 buffered output + 30dB
ch2: hydrophone 2 buffered output + 30dB
ch3: hydrophone 3 buffered output + 30dB

A total of 4 runs were made:
run1: transducer lowered & raised slowly
run2: transducer lowered & raised slowly
run3: transducer near the surface at discrete depths
run4: transducer near the surface at discrete depths

Runs 3 & 4 were made with the pinger transducer near the bottom of the ice in order to make the direct and the surface-reflected pulses interfere with each other. Data will be analyzed in the future.

lf1: 9.25-11.25 KHz, 20ms
lf2: 9.25-11.25 KHz, 40ms
lf3: 11.25-9.25 KHz, 20ms
lf4: 11.25-9.25 KHz, 40ms
lf5: 9.75-10.75 KHz, 20ms
lf6: 9.75-10.75 KHz, 40ms
lf7: 10.75-9.75 KHz, 20ms
lf8: 10.75-9.75 KHz, 40ms
lf9: (lf2+lf4)/2
lf10: lf2 & lf4 concatenated
lf11: lf2 & lf6 concatenated
lf12: lf5 & lf7 concatenated

lp1: 9.25-11.25 KHz, 20ms
lp2: 9.25-11.25 KHz, 40ms
lp3: 11.25-9.25 KHz, 20ms
lp4: 11.25-9.25 KHz, 40ms
lp5: 9.75-10.75 KHz, 20ms
lp6: 9.75-10.75 KHz, 40ms
lp7: 10.75-9.75 KHz, 20ms
lp8: 10.75-9.75 KHz, 40ms
lp9: (lp2+lp4)/2
lp10: lp2 & lp4 concatenated
lp11: lp2 & lp6 concatenated
lp12: lp5 & lp7 concatenated

PSK: 10 KHz, each step is 1ms long:
psk1: 1,1,-1,-1,1,1,-1,1,-1,1,1,-1,-1,-1,1,1,-1,1,1,1
psk2: 1,1,-1,-1,1,1,-1,-1,1,1,-1,-1,-1,-1,1,1,-1,-1,1,1

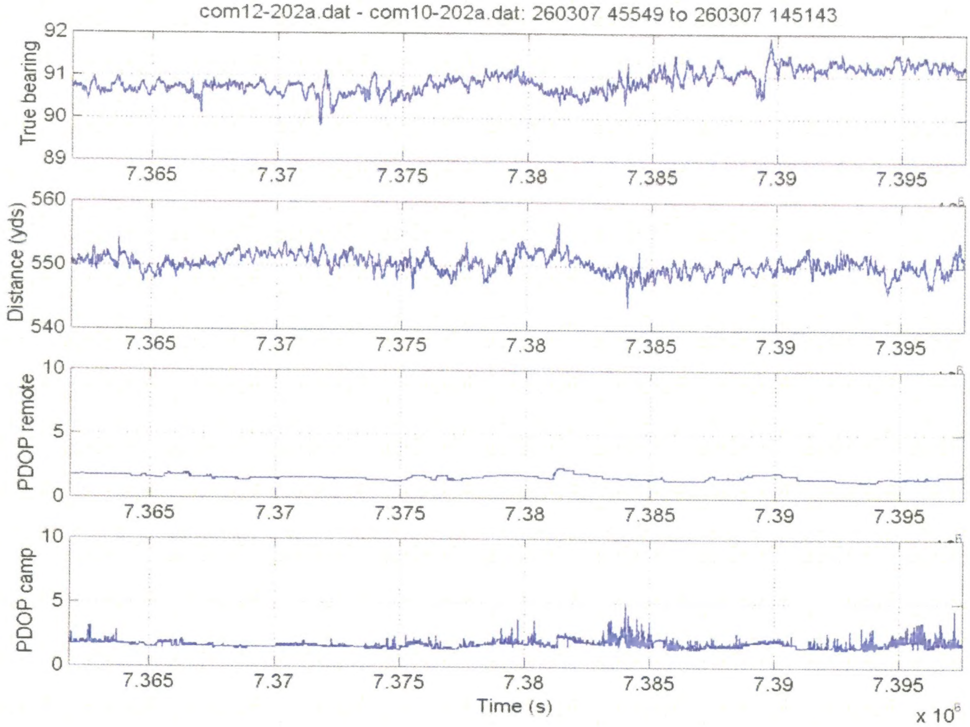
Table B-1. Test pulses transmitted. "lf" denoted linear frequency modulation and "lp" linear period modulation.

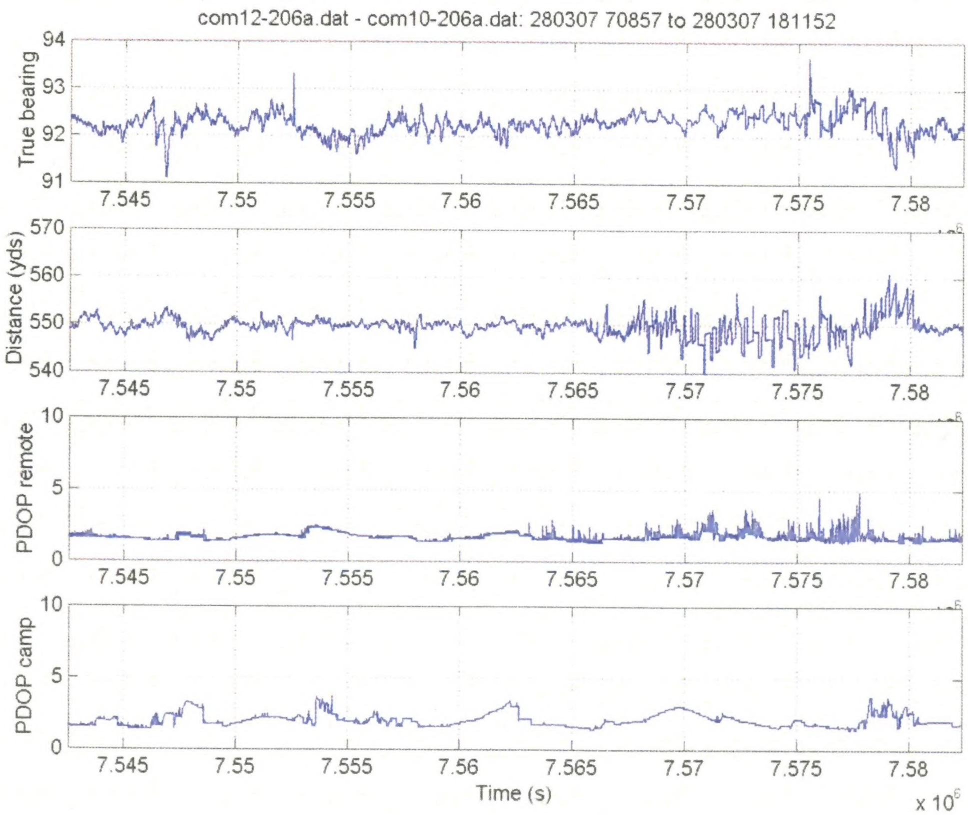
Appendix C.

GPS testing

In the past APL/UW had been called upon to track objects over an area larger than 1 array could cover. To handle a larger area, a second tracking array was installed at about 5 to 6 Kyds away from the camp. Cables were then laid from the camp to the remote hydrophones to bring the signals back. Acoustic survey was done to map the remote hydrophones into the tracking coordinate system. It was tedious work laying the cables. Not only that, survey needed to be redone if a lead opened up between the camp and the remote array. Worst, the cables could break if the lead becomes wide enough, resulting in the loss of the remote array.

To alleviate the problem, we did a feasibility test of surveying the hydrophones using consumer GPS receivers. If accuracy was good enough, then the survey can be done easily and conveniently using the GPS fixes. A set of GPS receiver (Garmin-15H, running in WAAS mode) and a radio-modem powered by a battery was placed at hydrophones 1 & 3. GPS fixes at 1 second intervals were continuously telemetered back to the camp and logged. At the camp fixes from another GPS, placed above the (0,0) hydro hole, was logged also. We then computed the range and bearing of the two remote GPS's relative to the one at the camp. Figure C-1a & C-1b show some of the result for the GPS placed at hydrophone #1 relative to the GPS at the camp. Although the PDOP's (Position Dilution of Precision) were excellent in general, the range had up to 10 yards of variation and the bearing 1 deg of variation. All these translate to errors in survey and therefore in tracking. Further processing and analysis of the GPS data to improve the results will be done in the future.





Figures C-1a, b. Range, bearing, & PDOP's between GPS's placed at hyd #1 & the (0,0). C-1a is from 3/26 and C-1b is 3/28.